Hard photon measurements at RHIC

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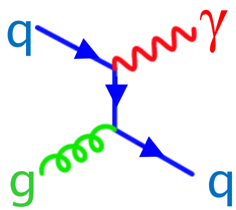
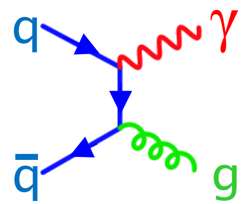
Direct photon sources in hadronic collisions

(*) Direct = not from decays of hadrons (π^0, η, K^0_s, ...)

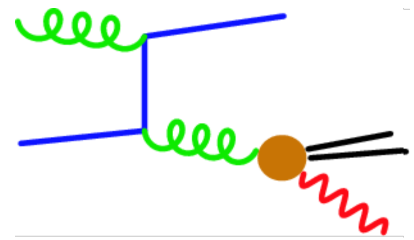
Direct photons in p+p



Compton



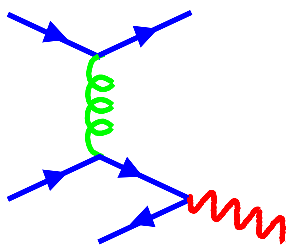
Annihilation



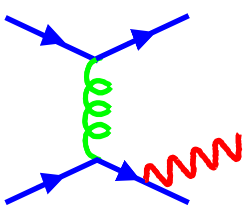
Fragmentation, see poster Ali Hanks

At high p_T and lowest order: Compton dominates.

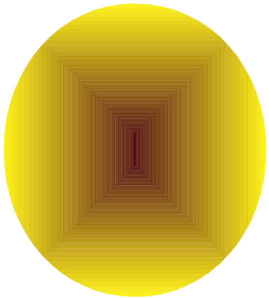
A+A adds medium



Jet conversion (Annihilation)



Medium induced bremsstrahlung



Thermal radiation?

Created in all phases of the collision

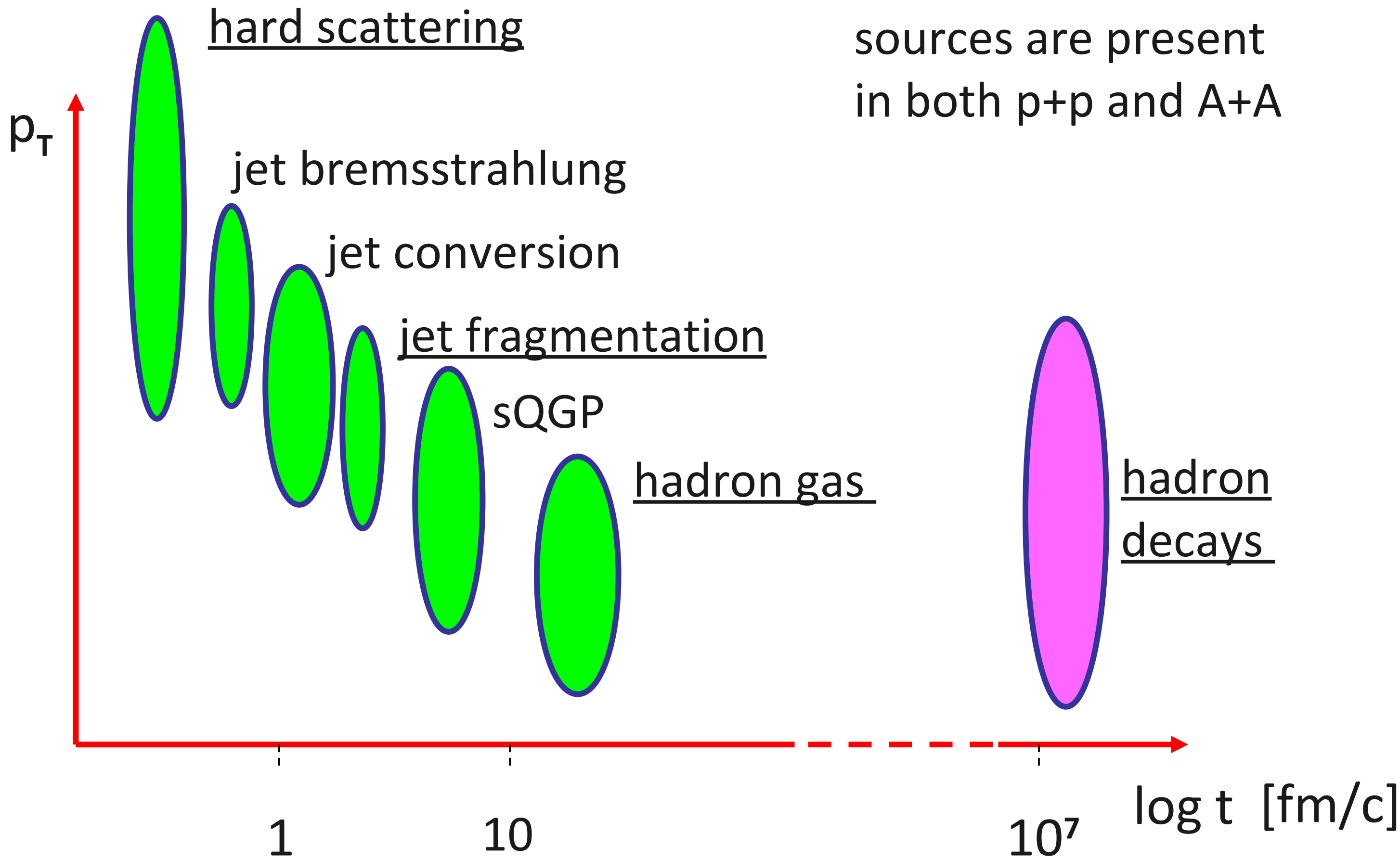
Once created, they survive ($\alpha_e << \alpha_s$) → time, temperature … history

But this also makes measurements hard to interpret

Direct photons see the whole collision history

All we measure is the projection to the p_T axis

dominated by hadron decay background up to medium p_T



The underlined sources are present in both p+p and A+A

Direct hard photons in p+p collisions

Low multiplicities, decay photons can be "tagged" (rejected) with high efficiency above 4-5 GeV/c
→ direct photons are identified

Good agreement with NLO pQCD (favors $Q_F=1/2p_T$ fragmentation scale)
→ factorization works

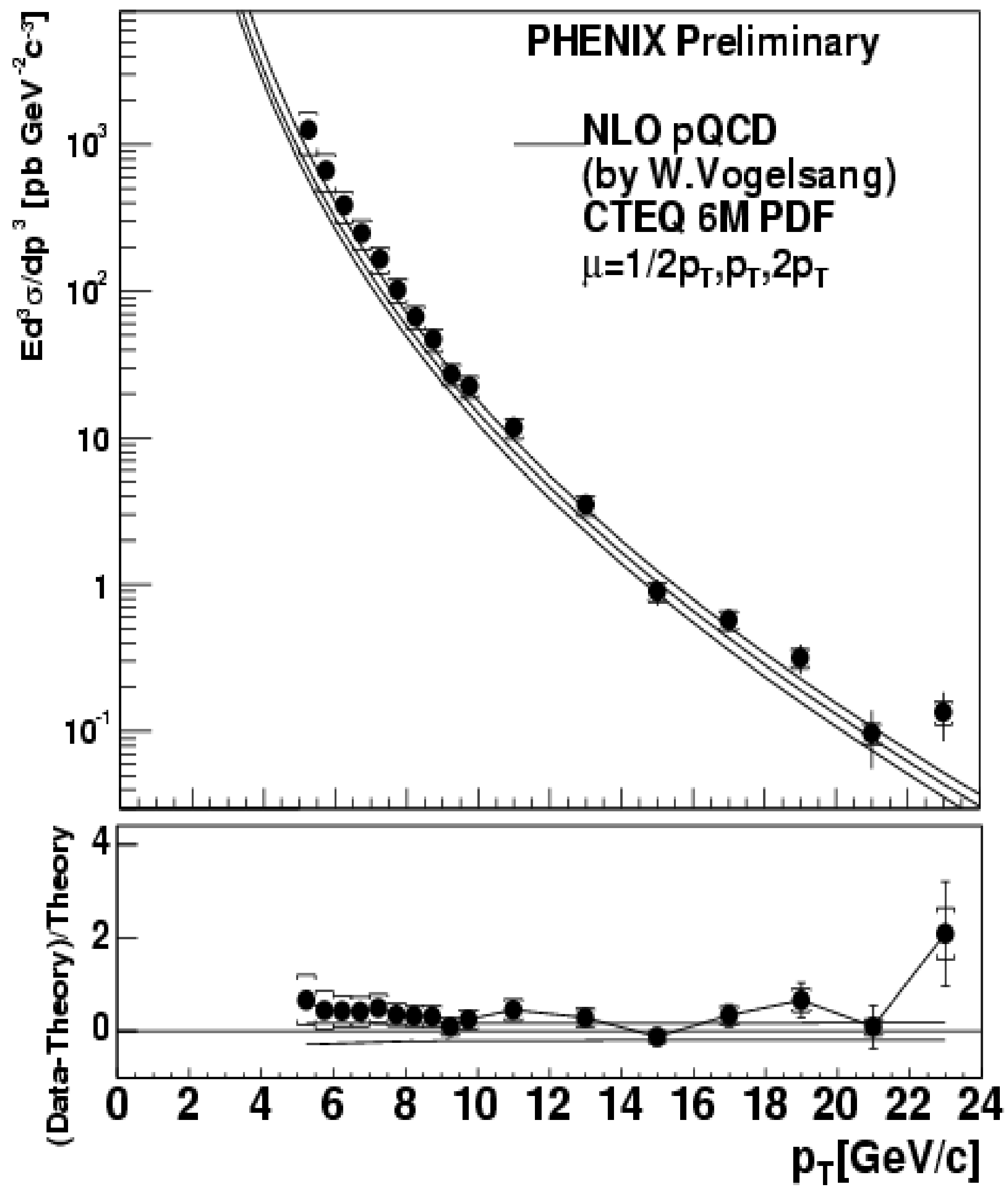
Since Compton dominates, **polarized gluon structure functions can be measured**

Much needed reference to establish what is different in A+A collisions

Reference from the same experiment: **reduced systematic errors**

Published Run-3 results: PRL 98 (2007) 012002

Run-5 (2005) data



Modifications in heavy ion collisions

R_{AB} ratios compare particle production in A+B collisions to elementary p+p interactions:

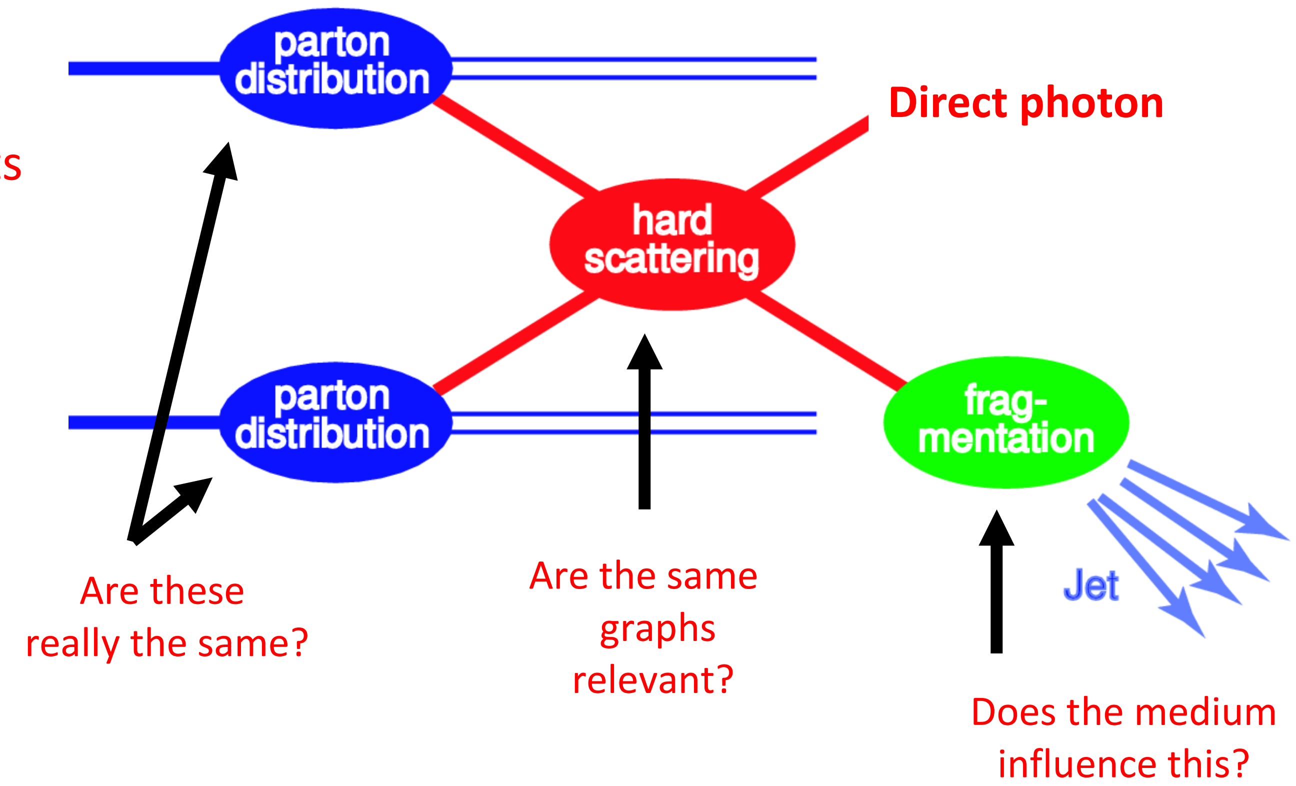
$$R_{AB}(p_T) = \frac{d^2 N^{\pi^0}_{AB}/dydp_T}{\langle T_{AB}\rangle \times d^2\sigma^{\pi^0}_{pp}/dydp_T}$$

T_{AB} is a relative nuclear thickness of A+B/p+p collision

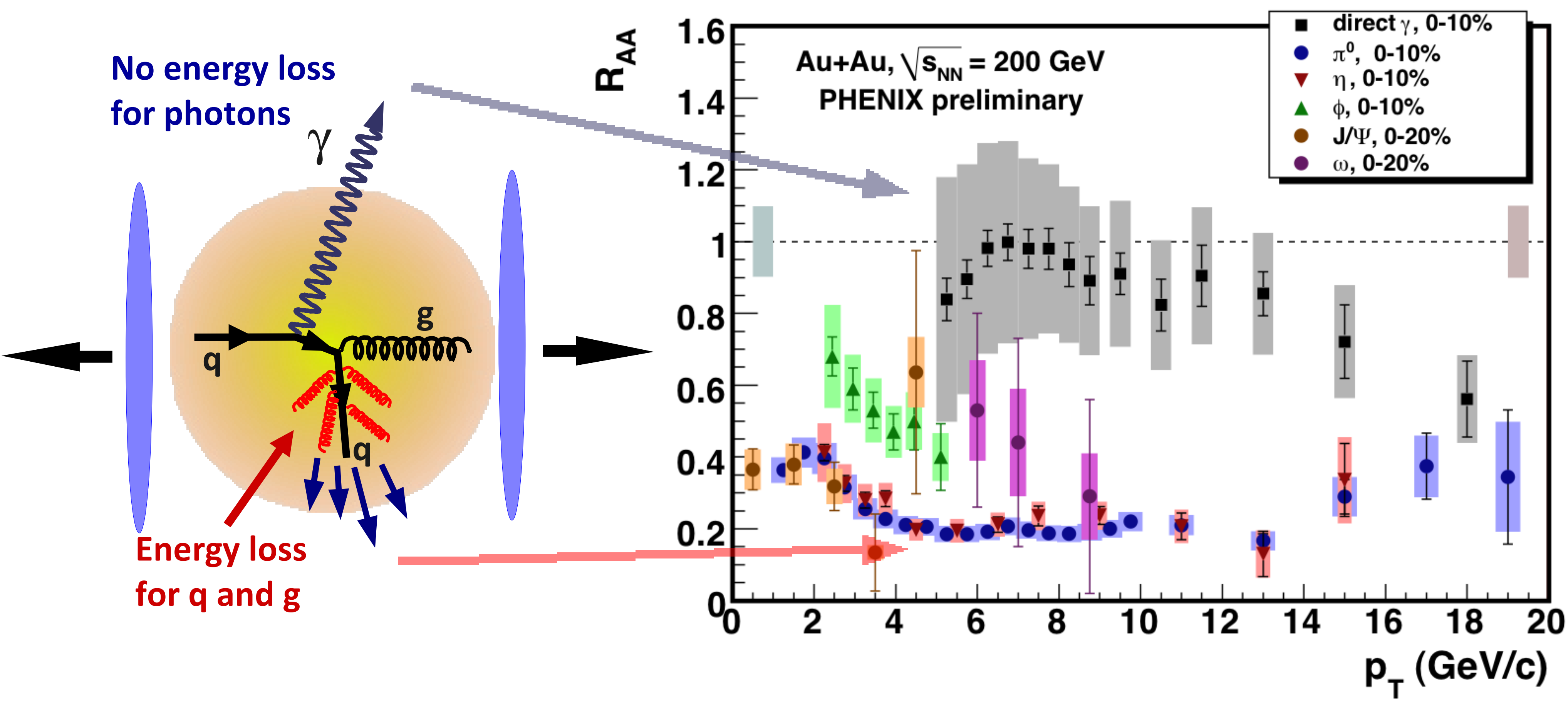
Questions in A+A collisions:

a) does factorization still work?

b) if it does, are the components different?



Hot medium effects



In the medium p_T range – strong suppression of mesons, no suppression for direct photons

→ evidence for strong medium induced effects (2002)

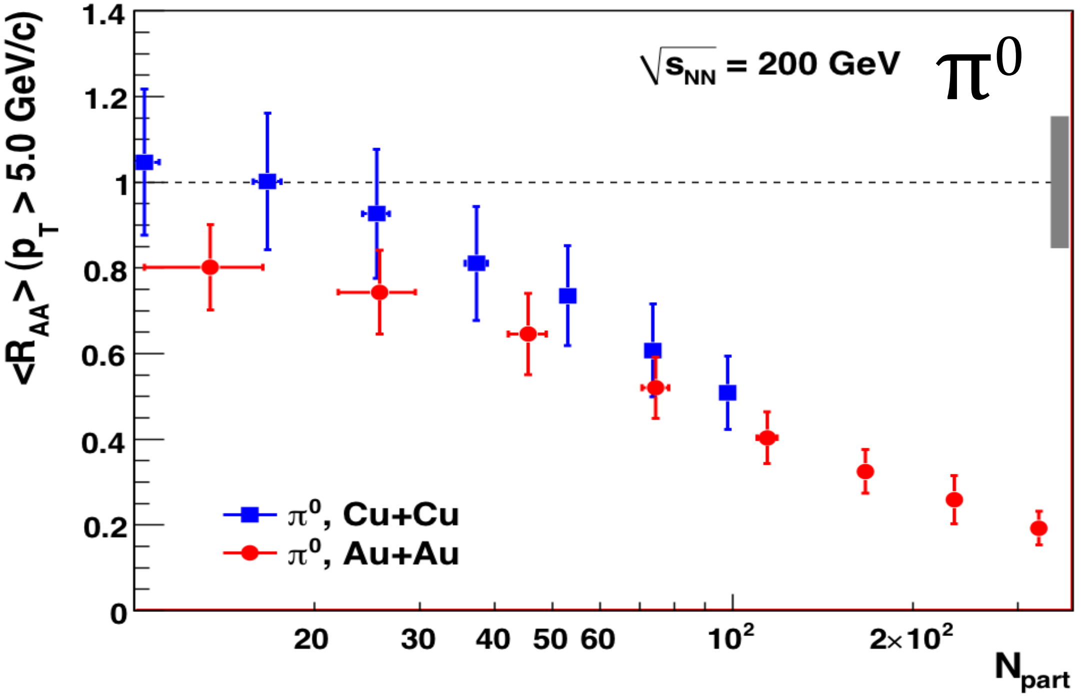
Direct photon suppression at high p_T in central Au+Au collisions (2006)

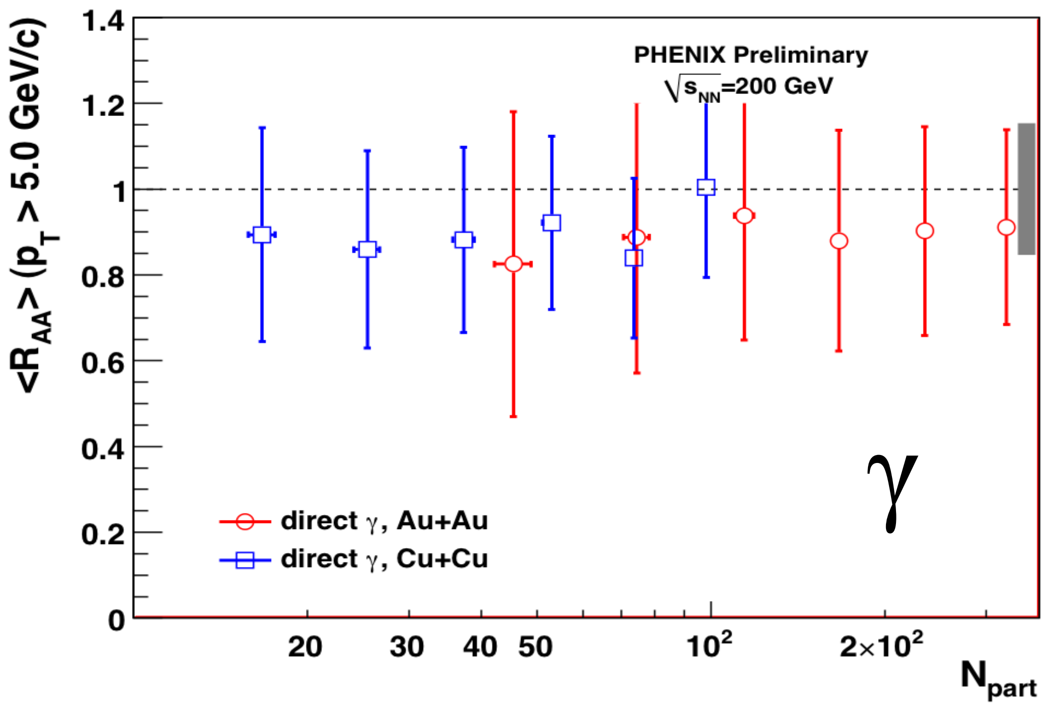
→ initial state effects?

Centrality and system size dependence

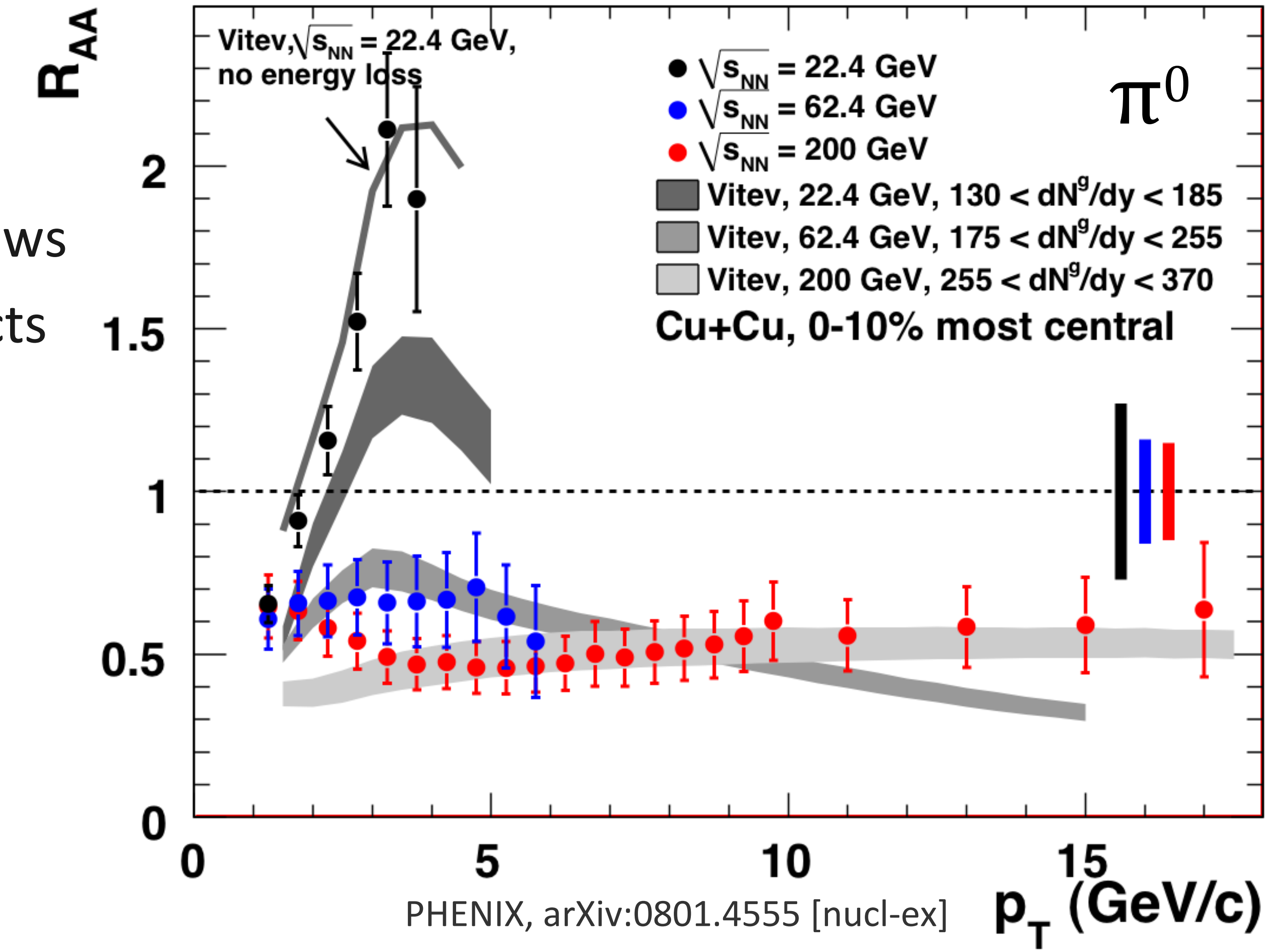
R_{AA} centrality dependence for both Au+Au and Cu+Cu shows progressive suppression of π^0 production

No suppression for direct photon production





Side note: energy dependence of π^0 suppression



R_{AA} of π^0 in Cu+Cu shows similar medium effects at 200 and 62.4 GeV

Little or no effect at 22.4 GeV

PHENIX, arXiv:0801.4555 [nucl-ex]

What happens above 20 GeV/c?

Talk by Yue Shi Lai today 4:10pm in the jet session

Low p_T “thermal” photons → initial conditions

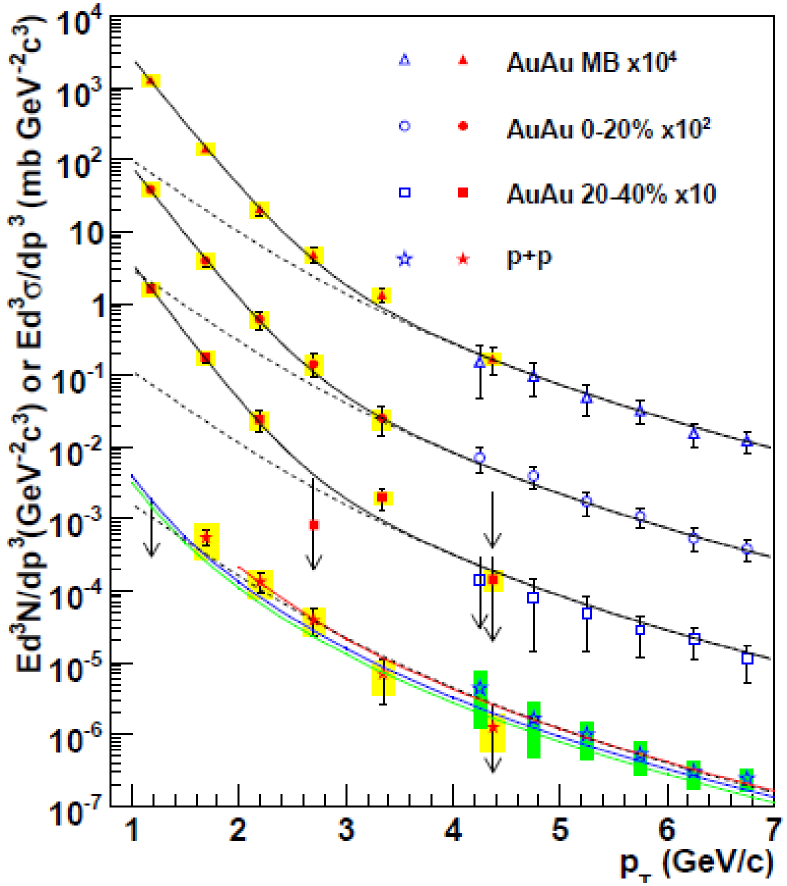
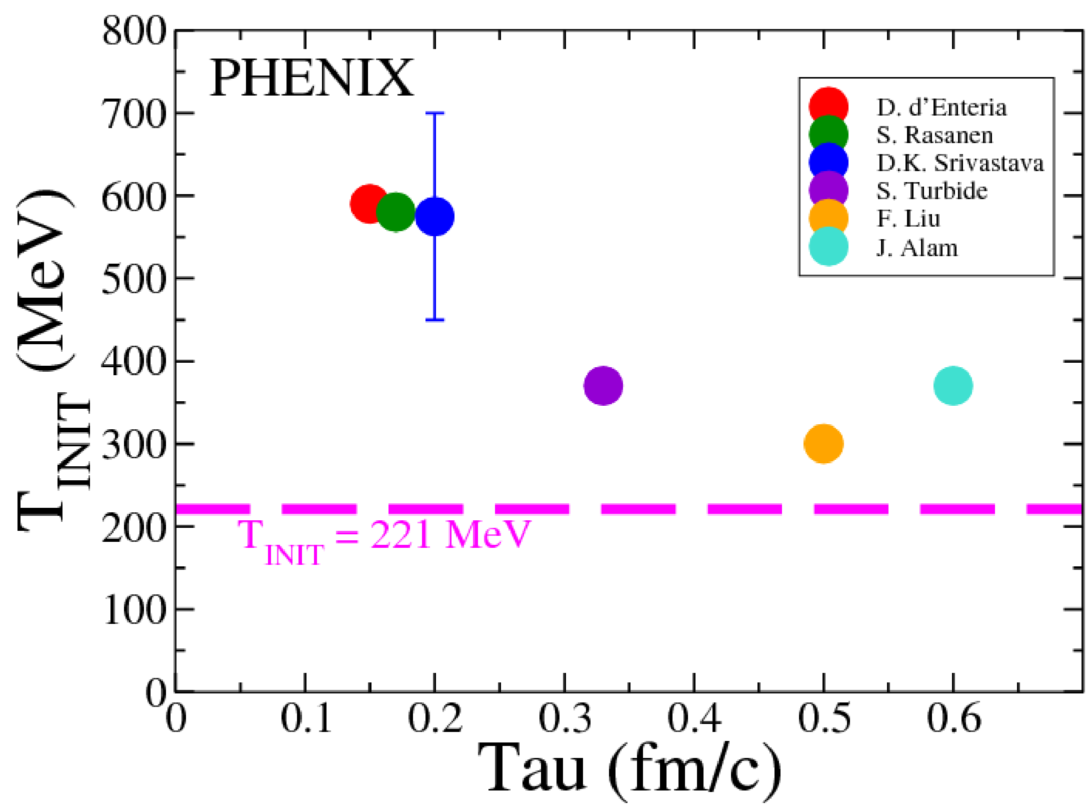


TABLE I: Summary of the fits. The first and second errors are statistical and systematical, respectively.

centrality	$dN/dy(p_T > 1\mathrm{GeV}/c)$	T(MeV)	χ^2/DOF
0-20%	$1.10 \pm 0.20 \pm 0.30$	$221 \pm 23 \pm 18$	3.6/4
20-40%	$0.52 \pm 0.08 \pm 0.14$	$215 \pm 20 \pm 15$	5.2/3
MB	$0.33 \pm 0.04 \pm 0.09$	$224 \pm 16 \pm 19$	0.9/4

PHENIX, arXiv:0804.4168v1 [nucl-ex]

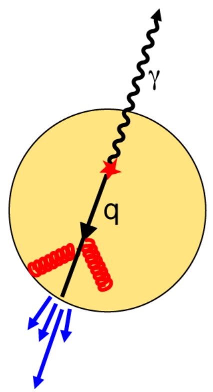


Hydro theories with different initial temperature and thermalization time describe the data reasonably well.

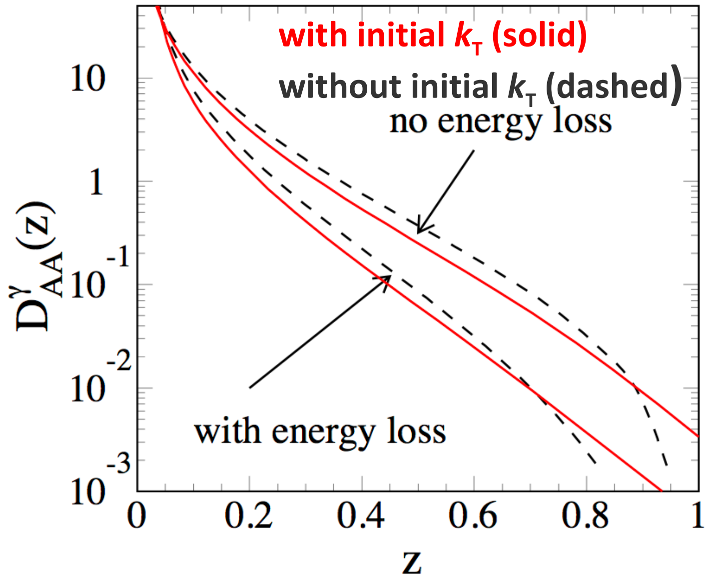
Even the lowest temperature estimate is above T_c

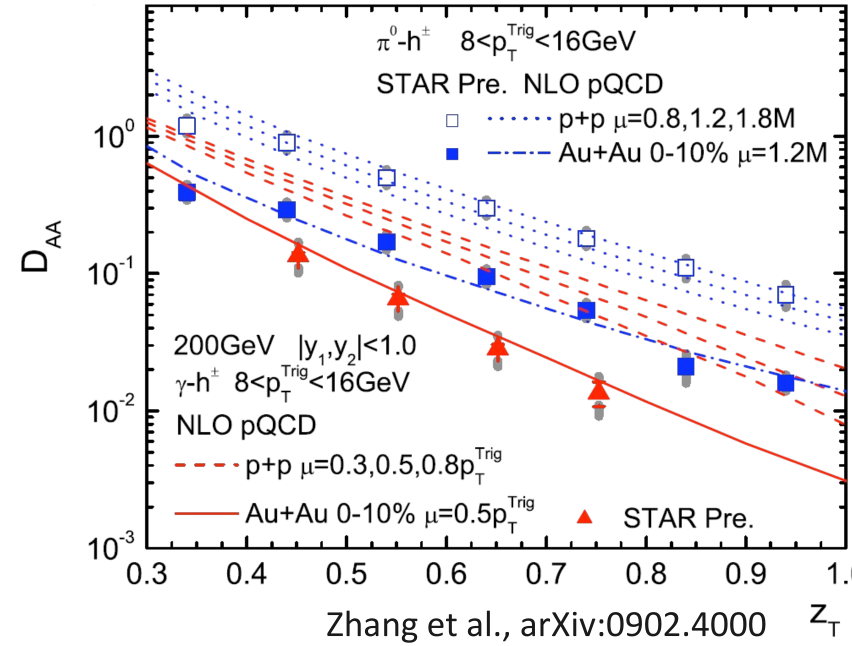
Talk by Axel Drees 11:20am today here

Photon-hadron/jet (ϕ=180) correlations



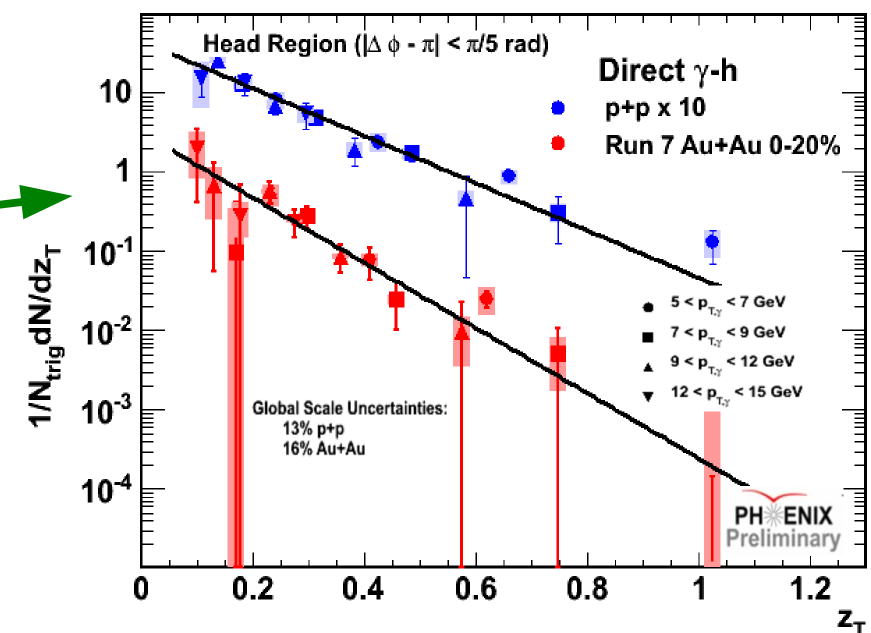
E(q) ≈ E(γ)





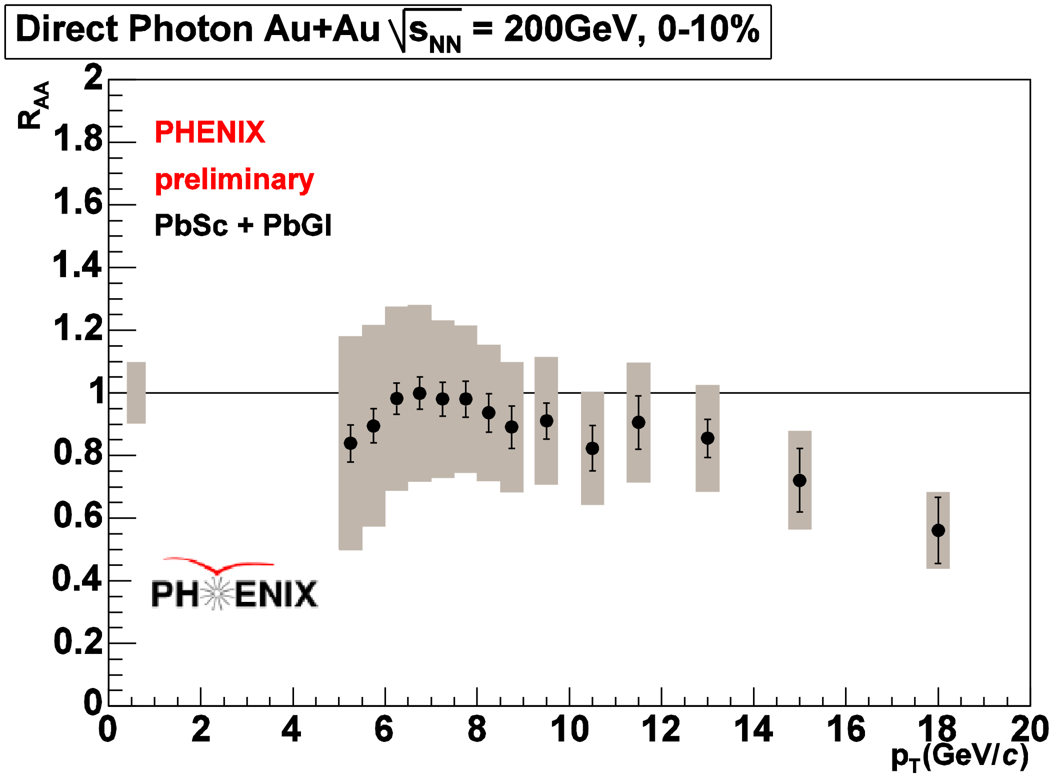
Zhang et al., arXiv:0902.4000

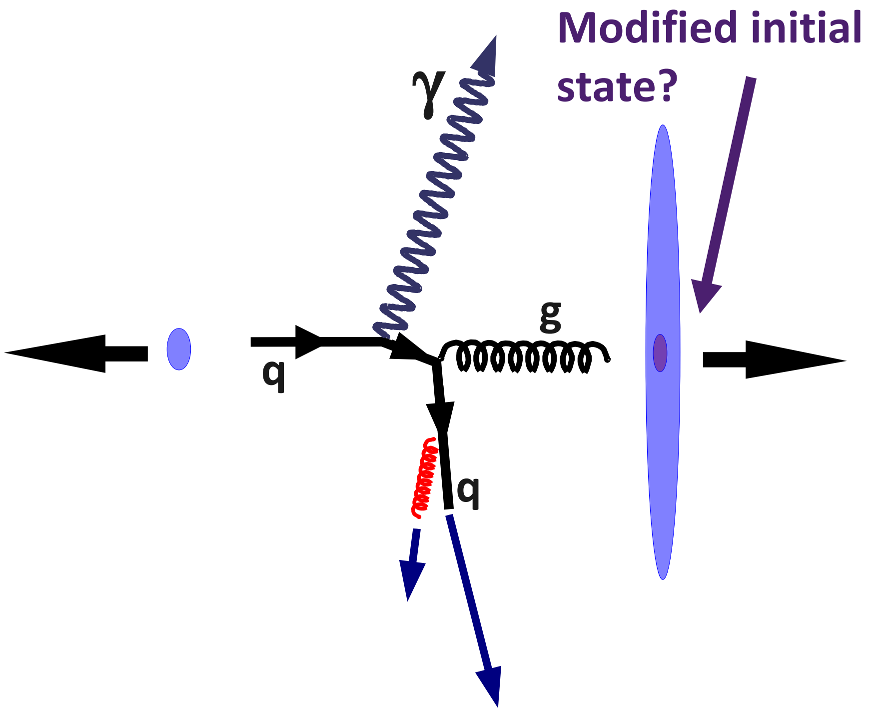
- photon calibrates the original jet energy
- γ-h → sensitive to energy loss mechanism
- $D_{AA}(z_T)$ = (gamma) triggered FF
- p+p slope of 6.89 ± 0.64
- Slope of Au+Au is 9.49 ±1.37
- Au+Au slope is ~1.3σ higher than p+p
- **See posters of Megan Connors and Matthew Nguyen**



z_T = p_T hadron / p_T gamma

Suppression of direct photons at high p_T



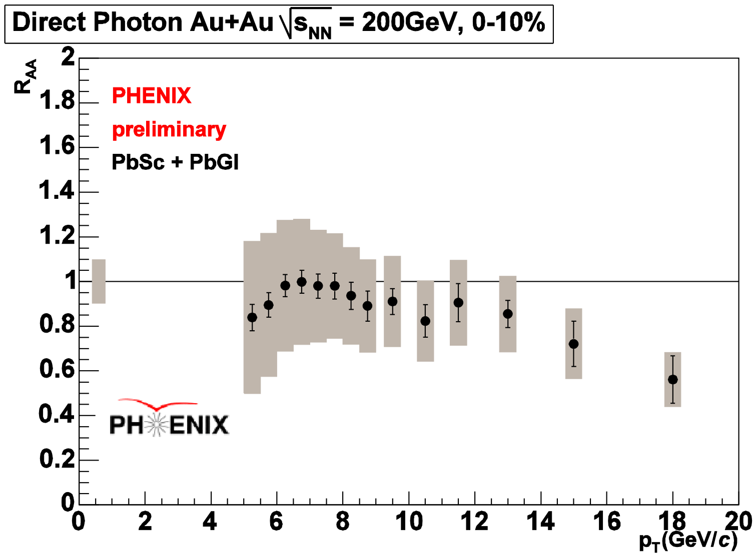


Experimental difficulties: Is the suppression real?

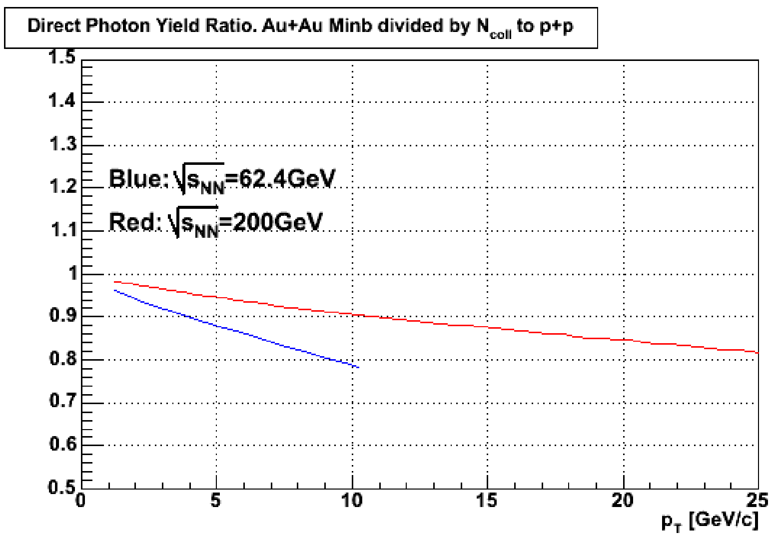
Isospin difference: Is p+p the correct reference?

Cold nuclear matter effects? Need d+Au measurement.

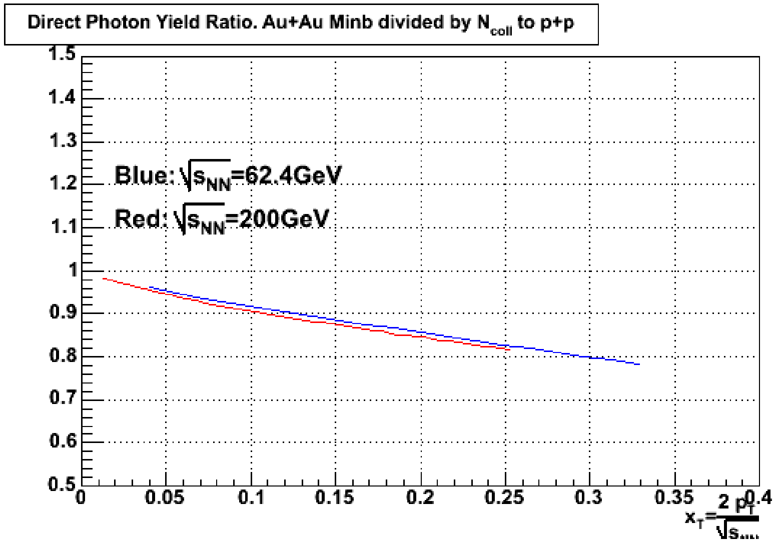
Is the suppression real? x_T scaling



x_T scaling to the rescue?

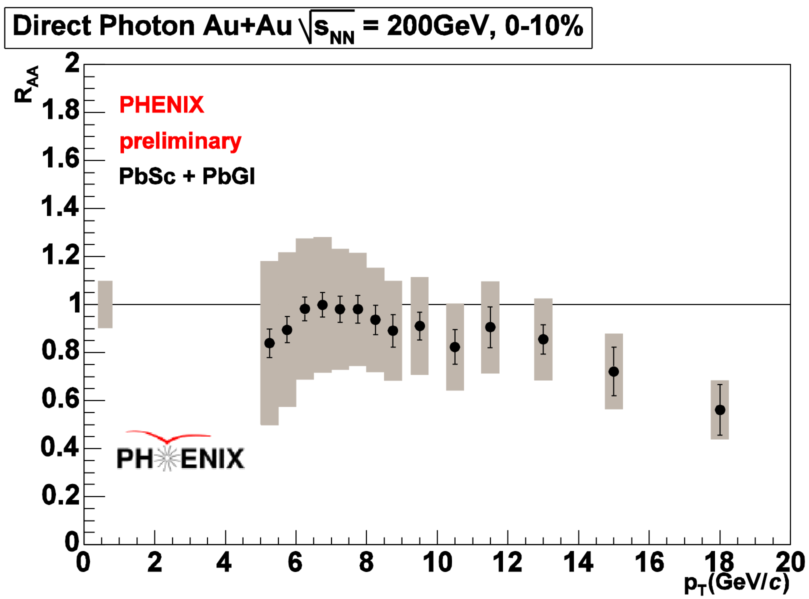


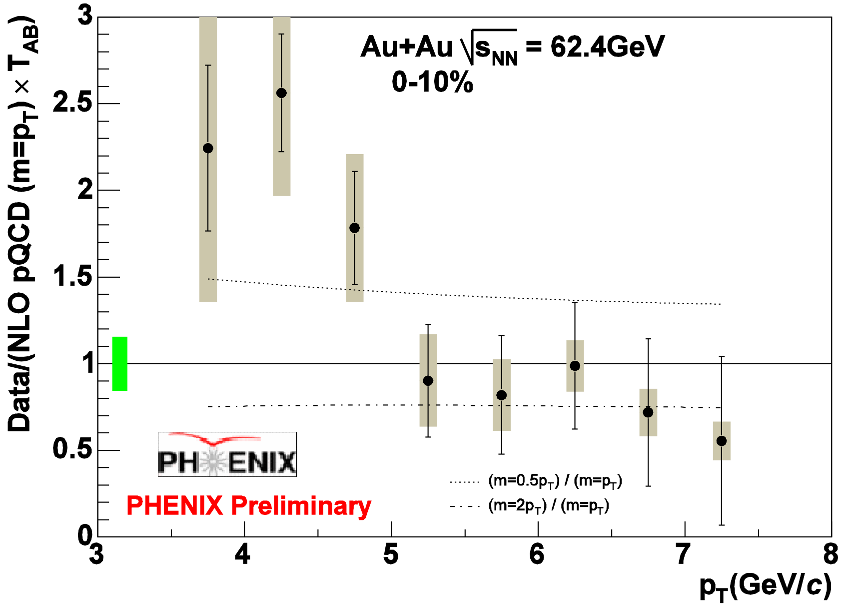
Unfortunately the suppression is seen in a region where we are very sensitive to detector bias: cluster merging, non-linearities.



However, the sources at intermediate p_T (like jet conversion) that are so far of unknown magnitude, come into play, too!

Is the suppression real? x_T scaling

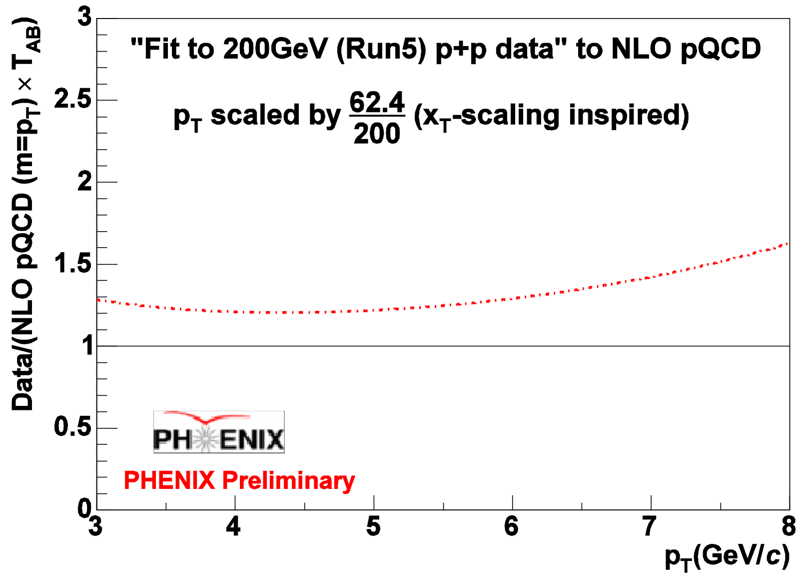




62.4 GeV data are scaled by theory limited by **statistics**

Remember 200GeV p+p data – closest to 0.5 pT scale, 20-30% differences

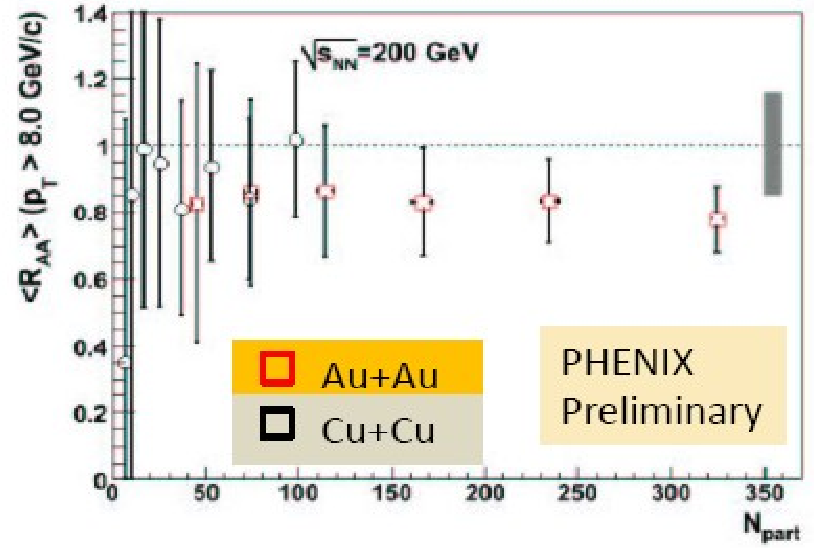
Is it real – stay tuned!



Is p+p the correct reference – isospin effect

The isospin effect – the charge difference between **uud** and **udd** - **should** be present, (almost) independent of centrality, but is this (and only this "trivial effect") what we see?

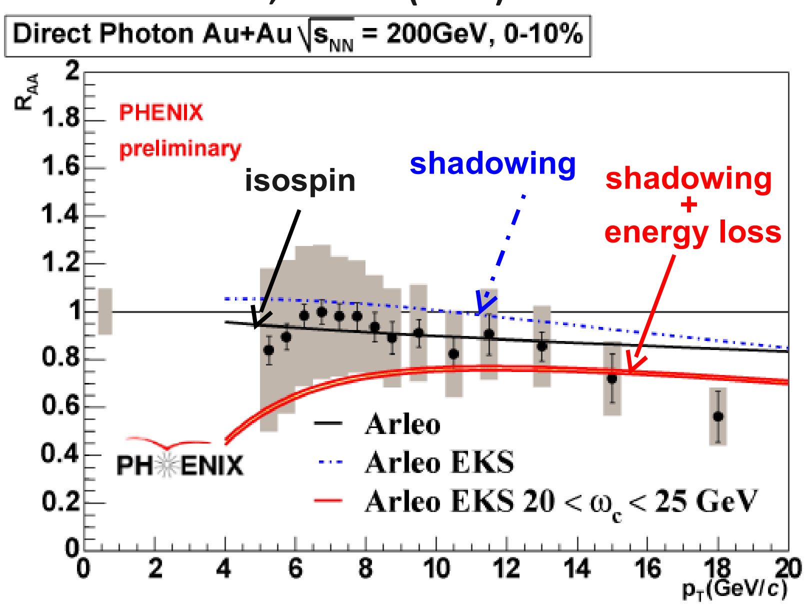
Do we see in addition some genuine photon suppression



Could d+d collisions help?

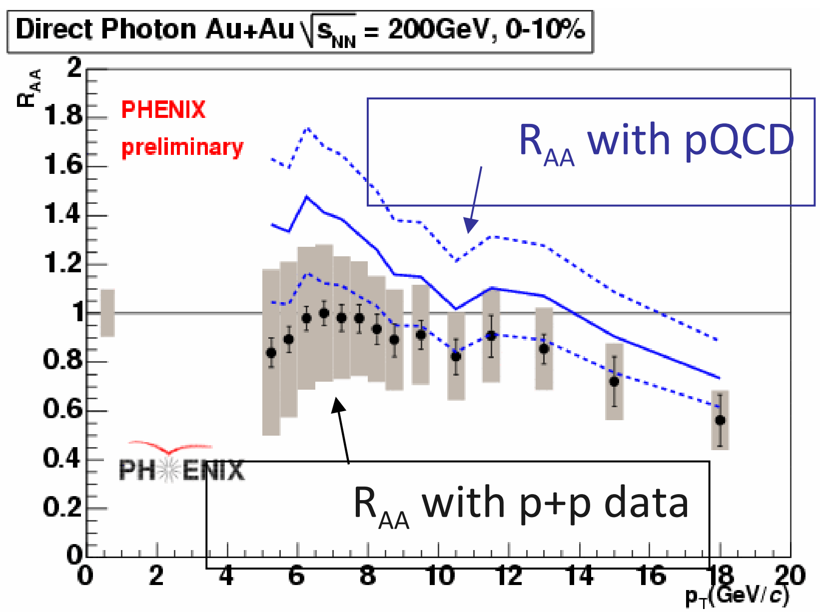
(One could tag pp, pn, nn collisions!)

F. Arleo, JHEP09 (2006) 015



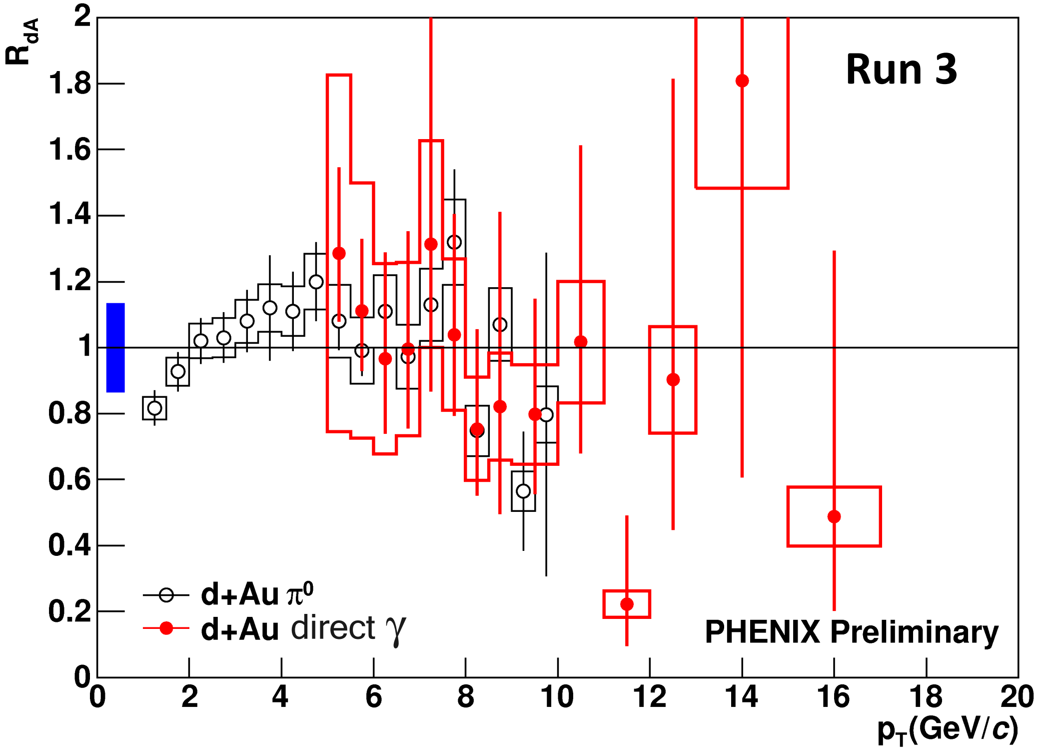
Also B.W. Zhang, I. Vitev, arXiv:0810.3194

W. Vogelsang, NLO pQCD + isospin



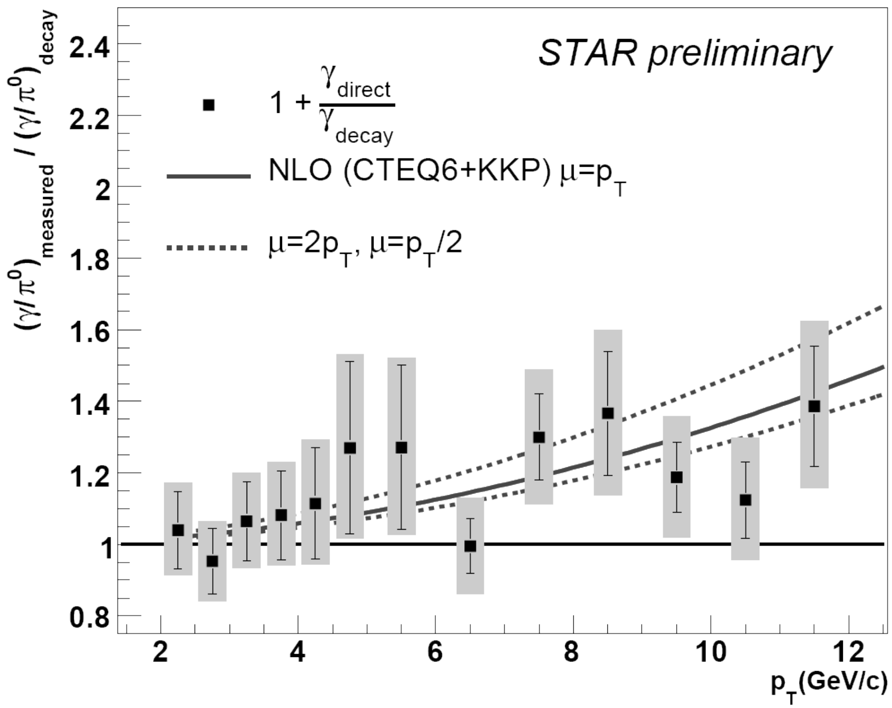
Cold nuclear matter effects: d+Au

PHENIX 2003 run results indicate $R_{dAu} \sim 1$, with large errors:



arXiv:nucl-ex/0701040

STAR double ratio consistent with NLO pQCD calculation

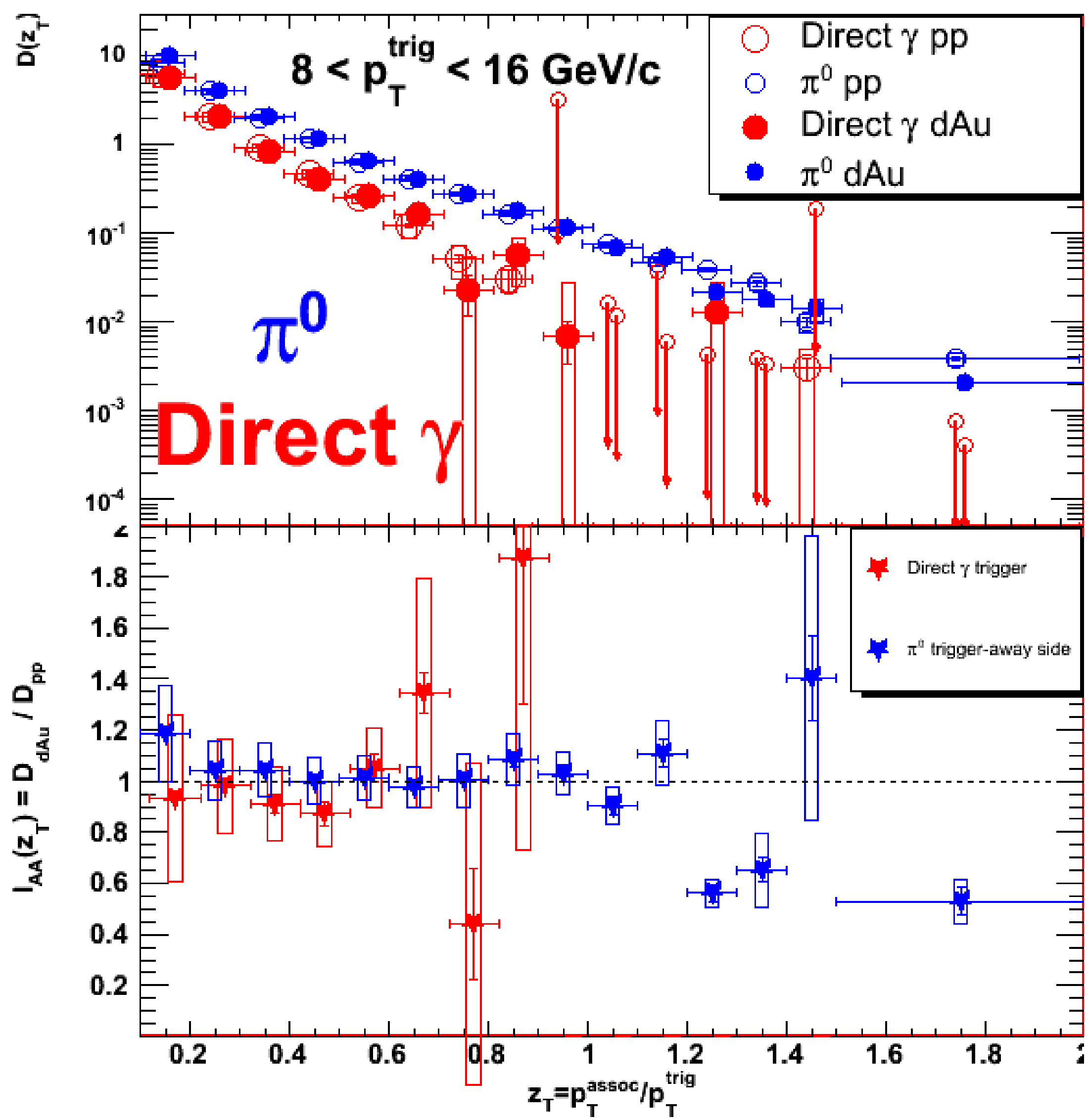


arXiv: nucl-ex/0701022

Direct γ and π^0 triggered yields in dAu (STAR)

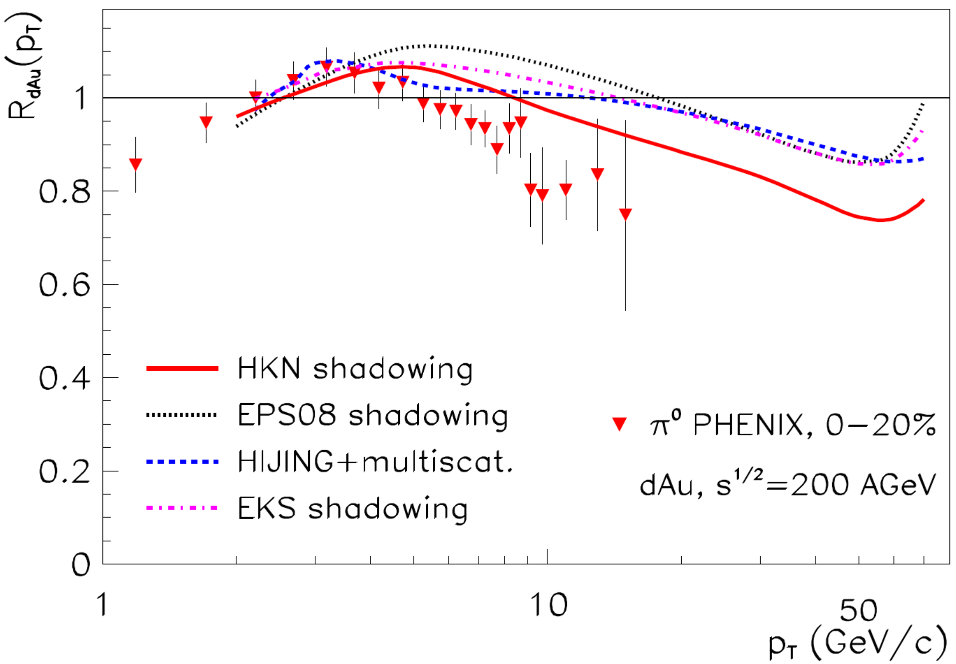
Ahmed M. Hamed, STAR, QM 2009

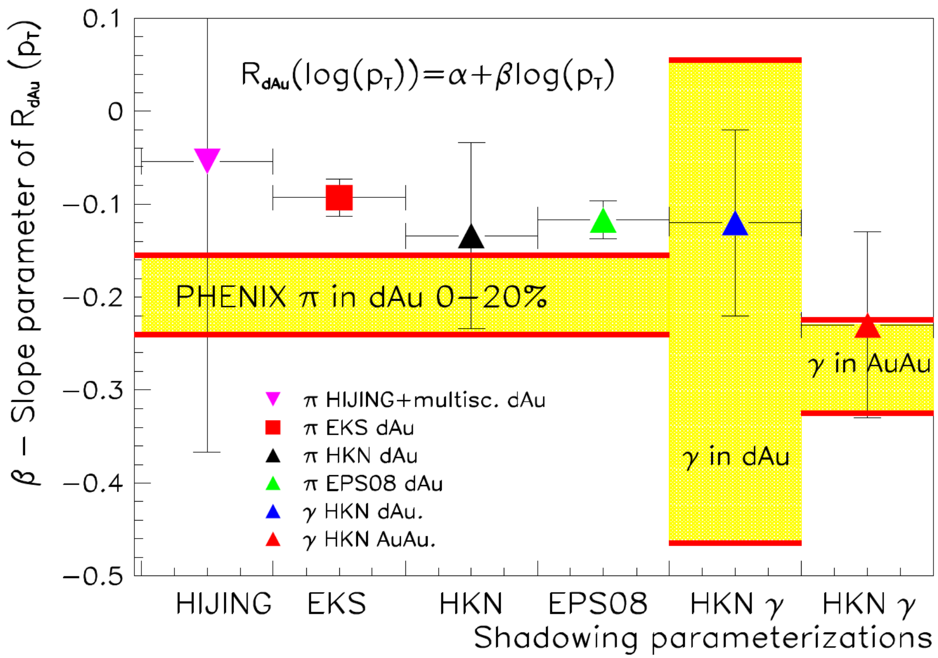
The p+p and d+Au D_{AA} distributions for γ and π^0 triggers agree within errors



Theory expects some suppression at high p_T

2003 data show hint of suppression in neutral pion R_{dAu}

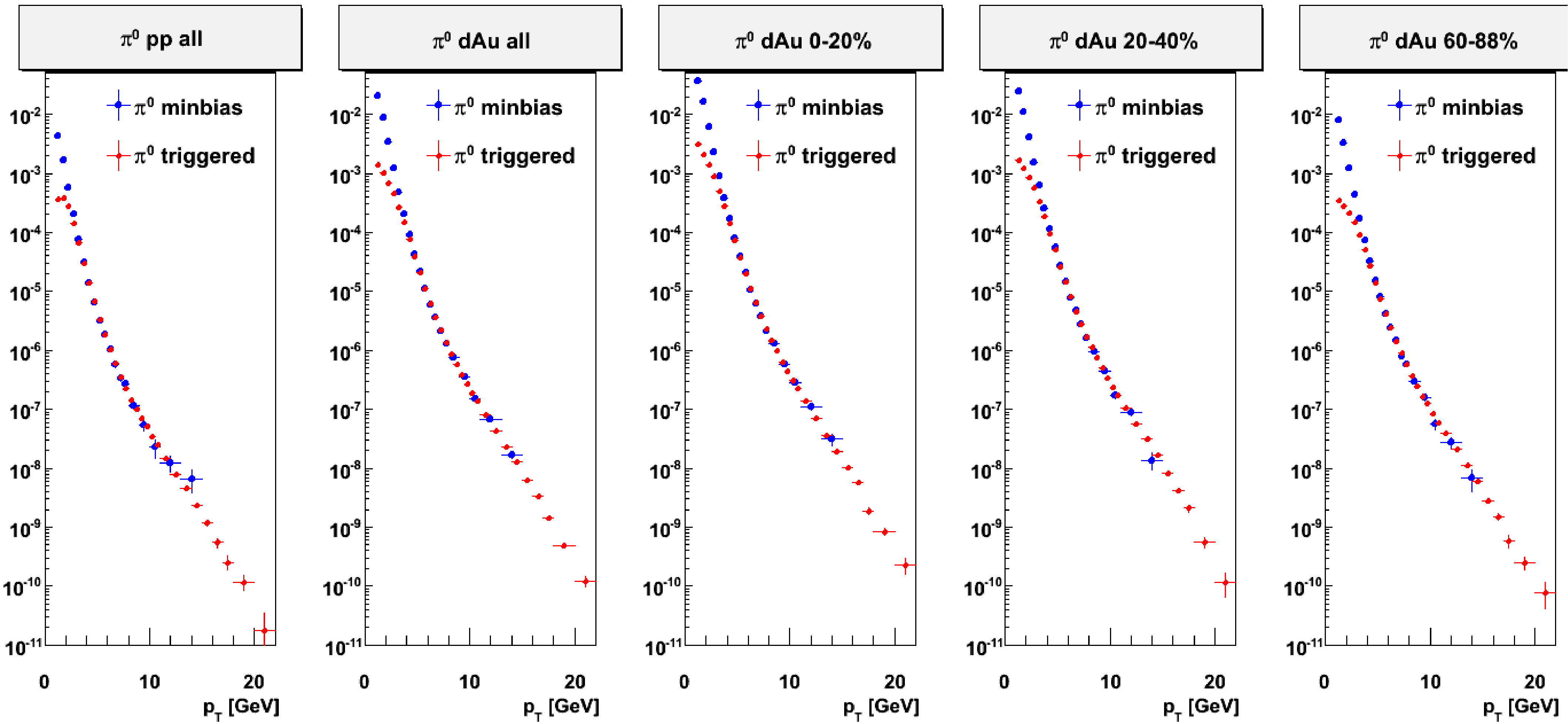




G. G. Barnafoldi, G. Fai, P. Levai, B. A. Cole and G. Papp, arXiv:0805.3360 [hep-ph]

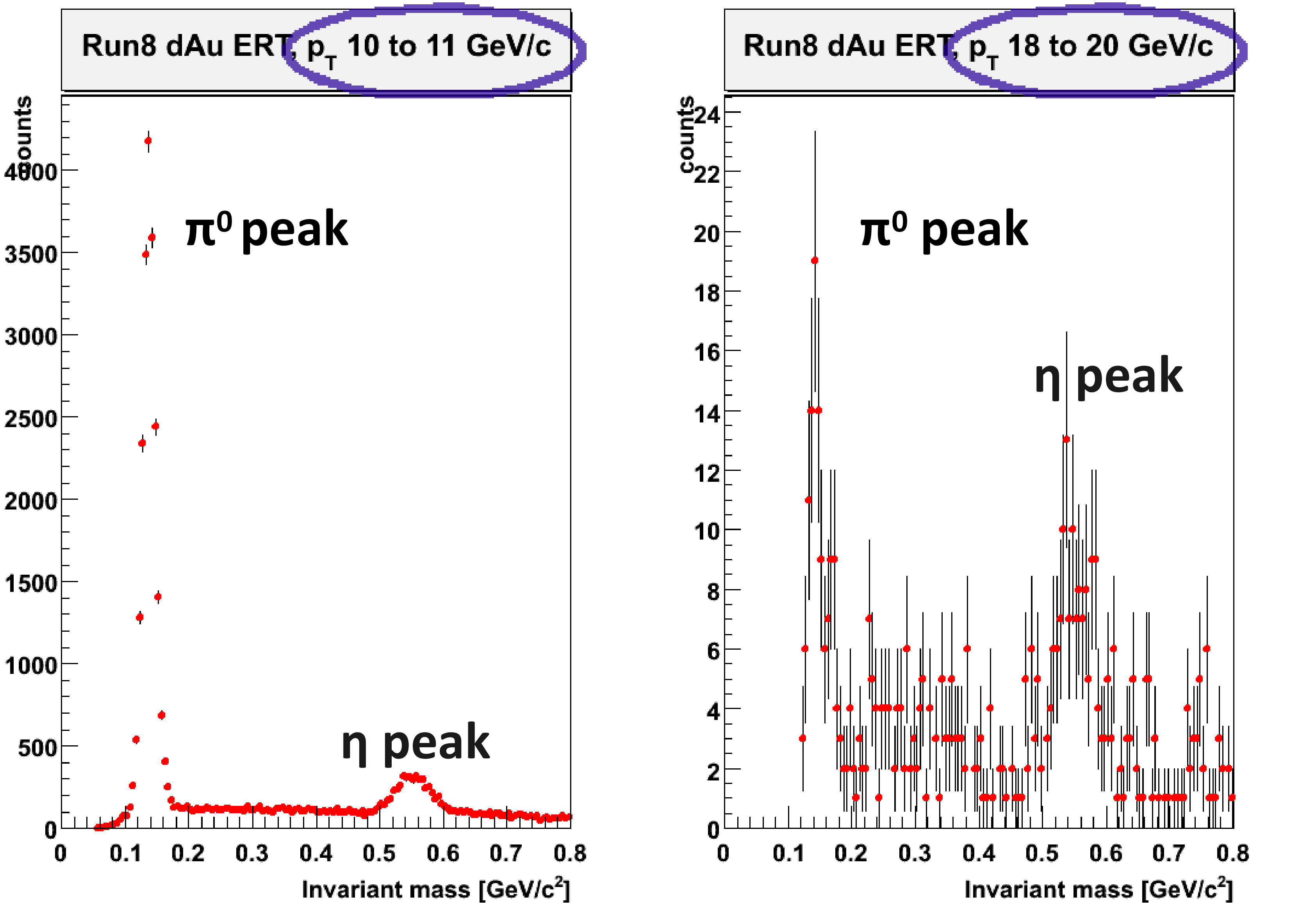
Year 2008 data: ~ 30x more statistics spanning ten orders of magnitude

	min bias	triggered
p + p	529 M	1170 M
d + Au	1649 M	3680 M



Ondřej Chvála, UC Riverside, chvala@bnl.gov

Invariant mass spectrum of gamma+gamma pairs in PbSc



R_{dAu} precision of 10-20 % at p_T ~20 GeV/c feasible with 2008 data for π^0, η, and direct photons

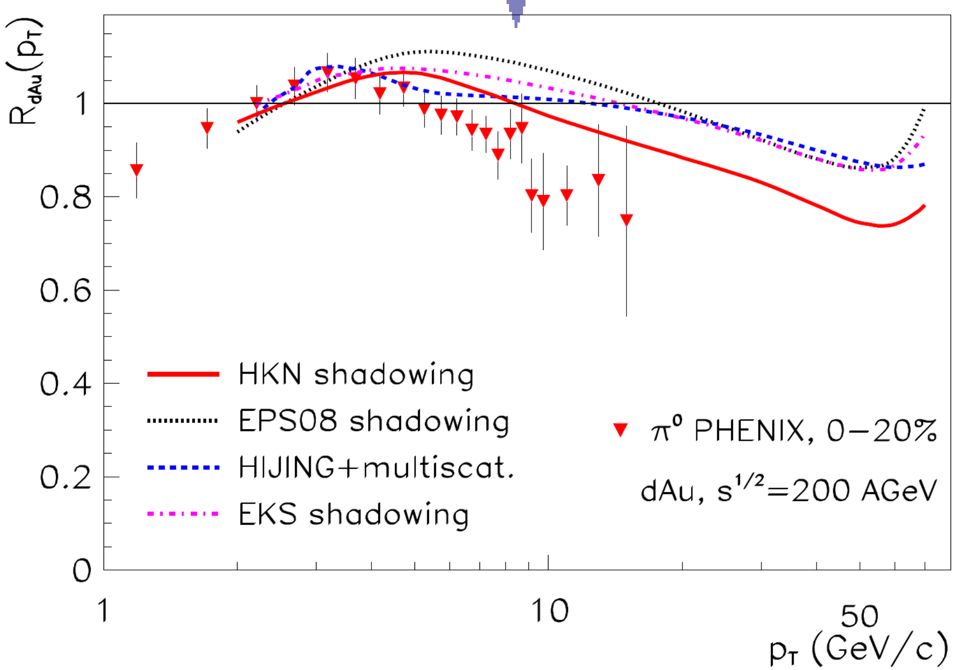
Conclusions

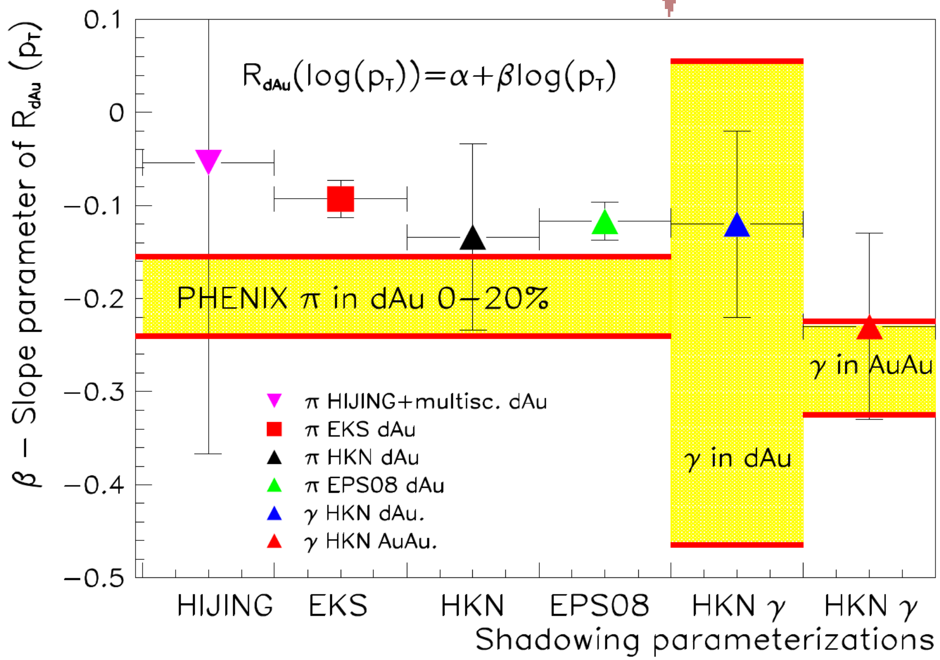
- Direct photons are versatile probes of hadronic collisions
- Low p_T suggests temperature above critical
- Hight p_T indicates isospin effect and suppression
- Gamma-jet correlations show a large change of D_{AA} slope
- New d+Au measurement will extend measurement to ~20 GeV/c with high precision

Cold nuclear matter effects? (CNM)

Quantitative description of medium properties necessitates understanding of CNM

2002 large hadron suppression in AuAu attributed to energy loss in medium ("final state effect")
2003 CNM control: first dAu results seem to confirm little or no change of initial state
2006 hint of direct photon suppression in central AuAu at high p_T (cannot be a final state effect!)
2007 final results from the 2003 dAu run show some suppression at high p_T
must be some initial state effect, but insufficient precision to quantify the effects
2008 new dAu dataset (~30 times larger) to extend the p_T range, decrease errors and quantify CNM
(modification of structure functions, shadowing, saturation, cold quenching etc.).





From: G. G. Barnafoldi, G. Fai, P. Levai, B. A. Cole and G. Papp, arXiv:0805.3360 [hep-ph]

Test of pQCD: world data on pp vs theory

NLO calculations agree with data over 9 orders of magnitude – except for one experiment

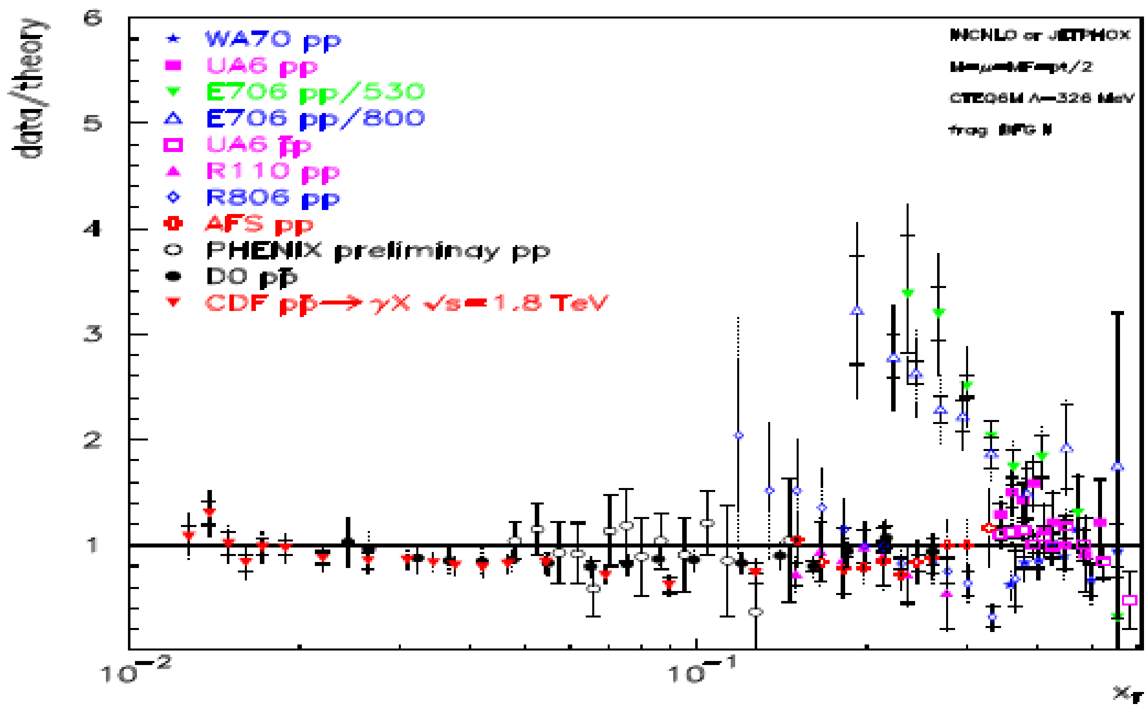
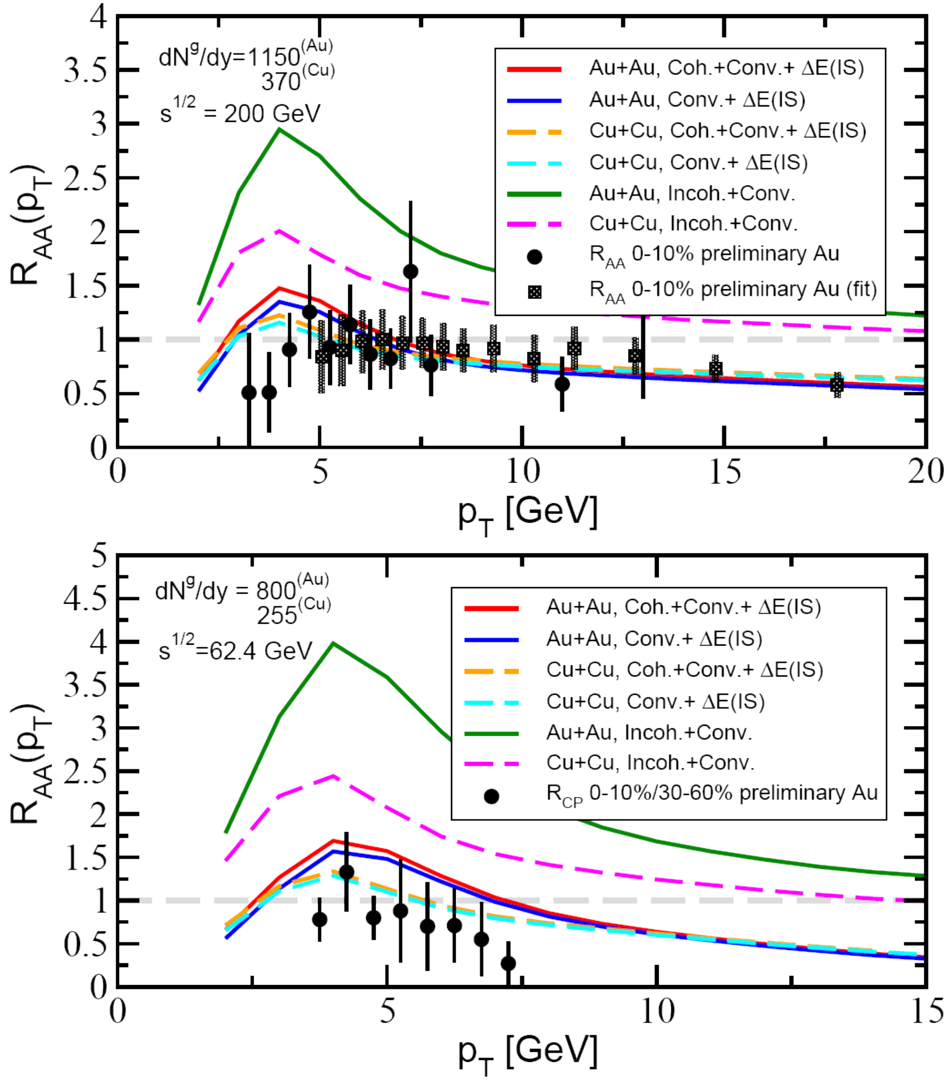


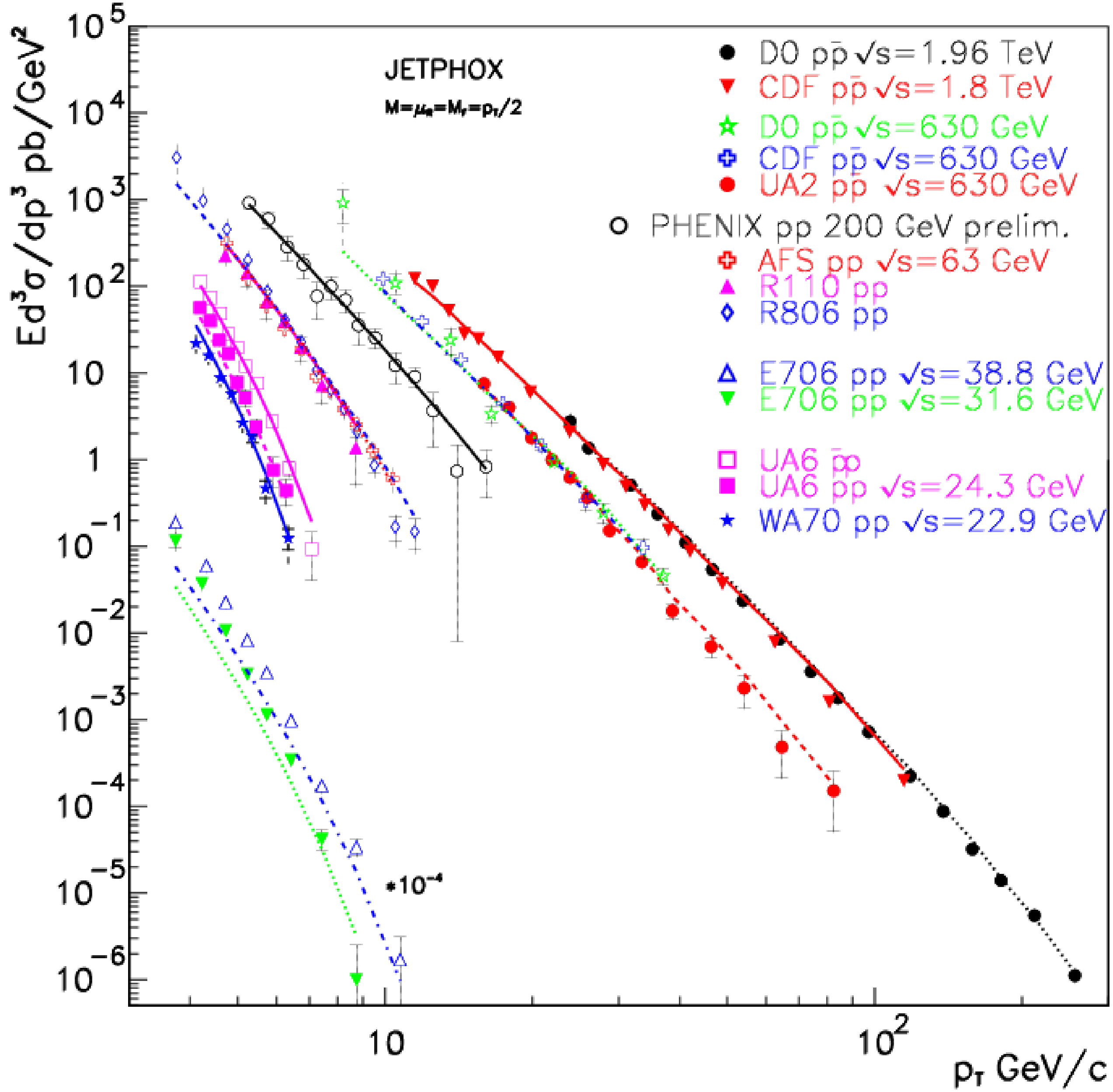
Figure 6: Ratios data/theory for collider and fixed target data with the scale $\mu = p_T/2$. For PHENIX and lower energy data the inclusive cross section is used while the isolated one is used for CDF and D$\emptyset$. Statistical erros only for PHENIX data.

hep-ph/0602133
Aurenche et al.

Ben-Wei Zhang, Ivan Vitev

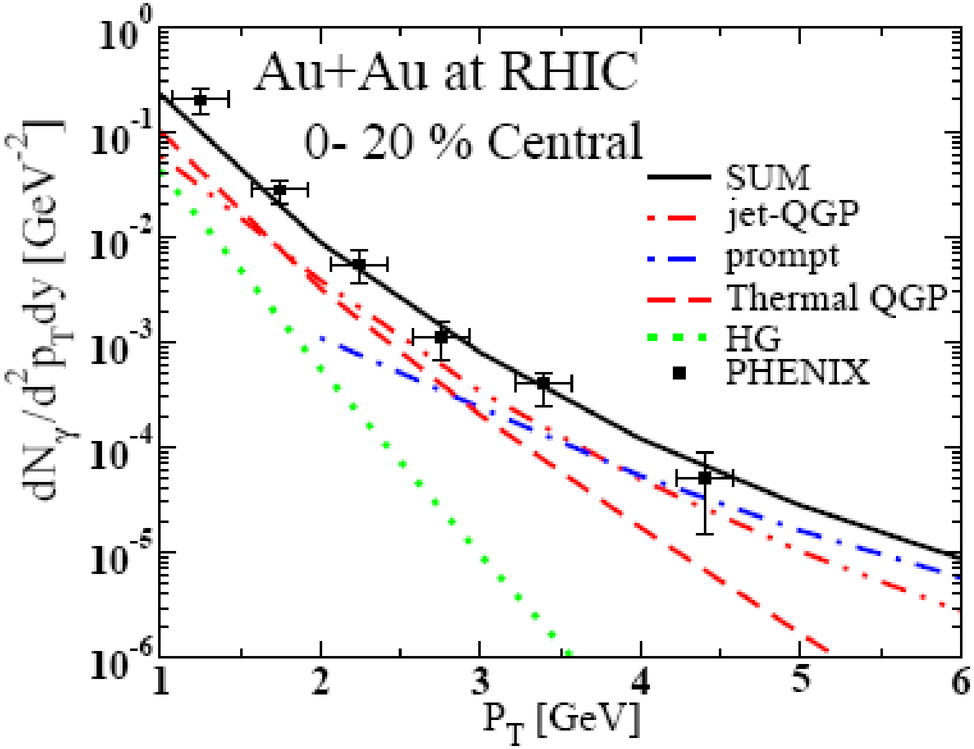
arXiv:0810.3194

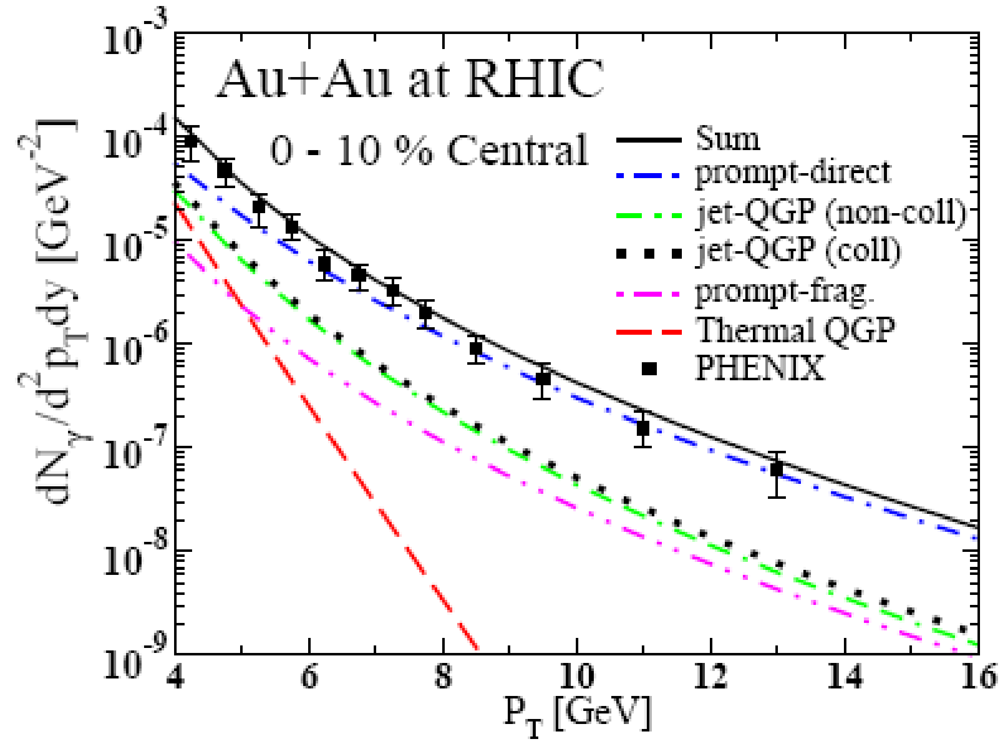




Aurenche et al. PRD 73 (2006) 094007.

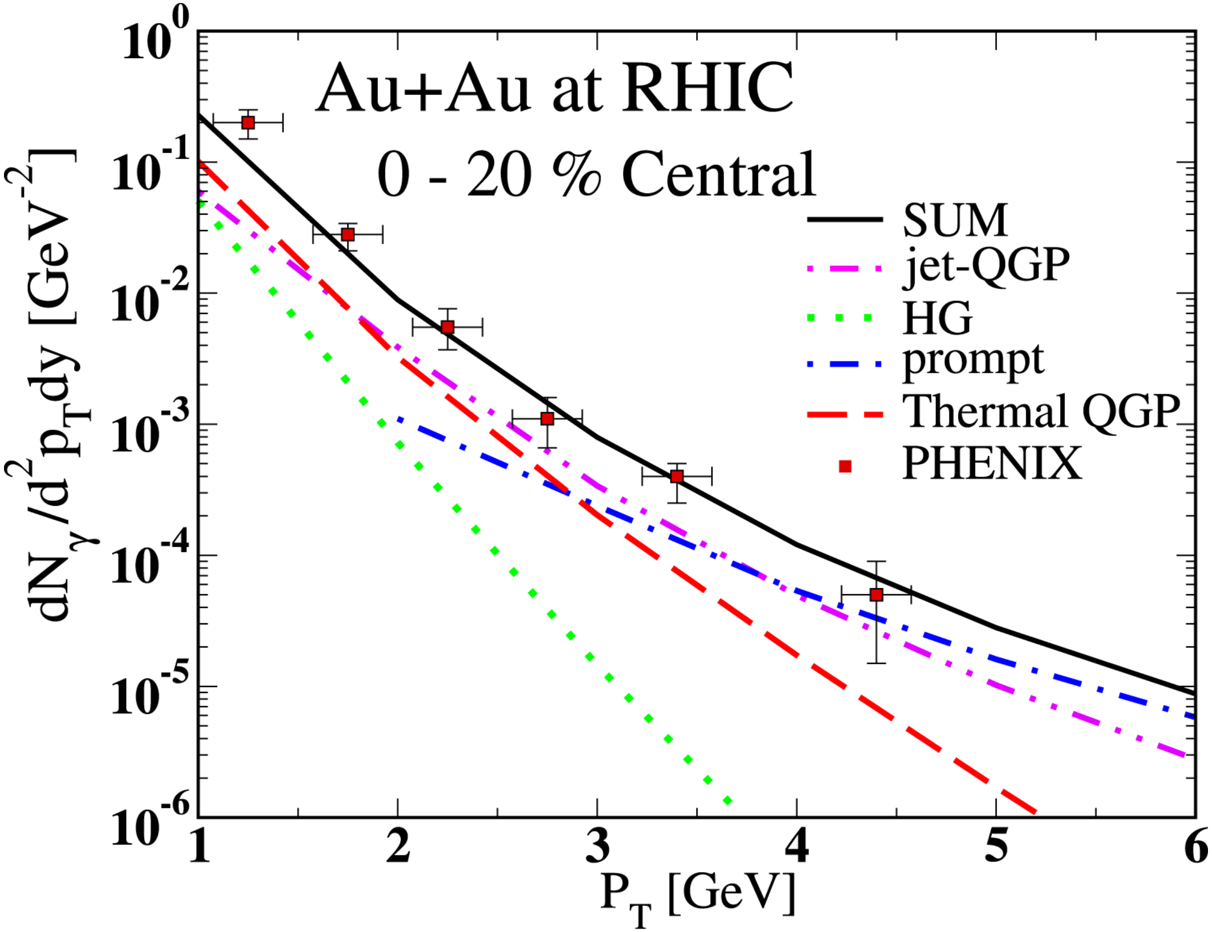
AMY and One-Stop Treatment of Jet-Quenching and Jet-Initiated Photons





Turbide, Gale, Frodermann, & Heinz, PRC77 (2008) 024909.

Model Comparison



C. Gale, arXiv:0904.2184v1

- Model space-time evolution with ideal hydro
- This calculation (arXiv:0904.2184v1)
  - Hydro starts early (τ_0 = 0.2 fm/*c*) to take pre-equilibrium photons into account
  - Thermal equilibrium expected at τ_0 = 0.6 fm/*c* (T_{initial} = 340 MeV)
  - Photons from jet-plasma interaction needed
- $T_{\text{initial}} > T_c \approx$ 170 - 190 MeV
  $\rightarrow$ evidence for the formation of a quark-gluon plasma

Similar conclusions for essentially all hydro models on the market

Photon2009 DESY/Hamburg, May 11 - 15, 2009

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